Biological Evaluation of Hemlock Woolly Adelgid At Allegheny Portage Railroad National Historic Site, Cresson, Pennsylvania March-June, 2009

Prepared by

Karen Felton, Biologist
and
Bradley Onken, Entomologist
USDA Forest Service
State and Private Forestry
Forest Health Protection
180 Canfield Street
Morgantown, WV 26505

Table of Contents

ABSTRACT 3
INTRODUCTION 3
Hemlock woolly adelgid 3
Hemlock Importance 5
METHODS 6
RESULTS 6
DISCUSSION 14
Management Considerations 14
Foliar Chemical Treatments 14
Systemic Insecticides 14
Biological Control 15
RECOMMENDATIONS 16
REFERENCES 18

ABSTRACT

On March 17-18 and June 30, 2009 personnel from the USDA Forest Service, Northeastern Area, Forest Health Protection, Morgantown Field Office conducted a survey to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* densities and to assess the need for treatment at Allegheny Portage Railroad National Historic Site (ALPO) in Pennsylvania. HWA is present in the Incline 6 to 8, Muleshoe, Incline 9, and Foot of Ten areas of the Park. No HWA was detected in stands located in the Summit Area (Main Unit of the Park) and in several of the higher elevation hemlock stands in the Incline 6 to 8 Area. Control of HWA on accessible, individual, high-valued, infested hemlock trees at ALPO is recommended to prevent future decline of hemlock tree health. The release of predatory beetles, when available, is also recommended as a biological control strategy and future control of HWA.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that feed exclusively on conifers. The family is divided into two genera: *Adelges* and *Pineus*. There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator complex associated with these native adelgids.

Native to Japan, the hemlock woolly adelgid (*Adelges tsugae)* is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999), both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). The HWA is currently established in 17 eastern states from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1998, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). In New Jersey

twelve years after initial HWA infestations, tree mortality reached more than 90% in some hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock. The winter generation, the sistens, develops from early summer to midspring of the following year (June-March). The spring generation, the progrediens, develops from spring to early summer (March-June). The generations overlap in mid to late spring.

The hemlock woolly adelgid is unusual in that it enters a period of dormancy during the warm summer months. Prior to dormancy, the nymphs produce a tiny halo of wool-like wax filaments surrounding their bodies. The adelgids begin to feed once cooler temperatures prevail, usually in October and continue throughout the winter months. As it matures this woolly covering increases in size and becomes more conspicuous. This woolly sac (ovisac) helps protect the insect and its eggs from natural enemies and prevents them from drying out. These ovisacs can be readily observed from late fall to early summer on the underside of the outermost branch tips of hemlock trees.

Figure 1. Hemlock woolly adelgid nymphs in dormancy.

Figure 2. Hemlock woolly adelgid ovisacs (woolly sac).

The ovisacs of the winter generation contain approximately 50 eggs, while the spring generation ovisacs contain about 25 eggs (McClure, 1989). The hemlock woolly adelgid also has a winged form that is produced by the spring generation. The winged form of this insect must complete its life cycle on spruce where its offspring would sexually reproduce before returning to hemlock. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent (McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and quantity of the food source, which is

associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999).

Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all life stages of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs and are committed to that feeding site throughout the remainder of its development. The stylet bundle is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001).

Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Unlike western North America and Asia where HWA is native, natural enemies capable of maintaining low-level HWA populations are nonexistent in eastern North America (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to have some degree of resistance because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002).

In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000).

There are 20 hemlock-hardwood stands totaling approximately 100 acres at ALPO. Some of the stands have cultural and/or natural resource values, based on watershed importance, stand composition, and trail locations. The Park has assigned priority rankings and treatment considerations based on individual management objectives and options for each stand. As hemlock trees die there is a concern for the negative impacts to the cultural and natural resource values of the stands, as well as, the increased potential of hazard trees and influx of invasive plants at the Park.

METHODS

The survey method used for this evaluation of HWA populations was based on the sampling plan developed by Costa and Onken (2006). This sampling plan measures the infestation level of the stand rather than individual trees. A strong relationship has been established between the percentage of trees infested and the number of adelgids found on branches. The sampling plan gives users a quick and precise way to both detect and characterize the severity of an infestation by determining the percentage of infested trees. The maximum number of trees to sample is set at 100, but as higher numbers of infested trees are encountered, substantially less sampling is required. When nearly all of the trees contain adelgids, only eight trees need to be sampled.

In addition to the stand level assessment, qualitative information regarding HWA densities on individual trees was also collected. On each branch, HWA densities were visually classified on each branch sample as heavy, moderate, light or none based on an estimated percentage of tips with adelgid present as follows:

Heavy (H) = >50% infested tips
Moderate (M) = 50% to 25% infested tips
Light (L) = <25% infested tips
None (N) = 0% infested tips

RESULTS

A total of 16 hemlock stands were survey at ALPO (13 surveyed by FS personnel and 3 surveyed by ALPO personnel) in the following areas of the Park: Summit Area, Incline 6 to 8, Muleshoe Area, Incline 9, and Foot of Ten. The hemlock stands are represented in Figures 4a-c, and a summary of stand information for all 20 hemlock stands at ALPO and survey data is presented in Table 1.

No HWA were observed in stands 42, 39, 56, 266, 143, 157, 35, and 33. Stand level infestations ranged from 0 -100 percent. Hemlock stands located in the middle of Incline 6

to 8 and continuing southeast to the Foot of Ten area have established HWA populations. HWA densities within tree were observed to range from none to heavy between the survey areas.

Infested hemlocks in stands 204, 32, 171 and 168 exhibited stunted new tip growth and some tip die-back. Non-infested trees elsewhere were healthy and producing abundant new growth.

Figure 3. Stunted and no tip growth on hemlock trees in stand 204 at ALPO, June 2009.

Table 1. Summary of hemlock stand information and survey data at ALPO: 2009

Location	Stand Number Surveyed	Park Acres	Relative[1] HWA Density/tree within Stand	Stand[2] Level Infestation (% trees infested)	Tree Health	Priority	Stand Type	Treatment Options
Summit Area	42	3.8	N	0	Healthy -New Growth	Medium	Hemlock-Northern hardwood	chemical/biological
Summit Area	39	2.1	N	0	Healthy -New Growth	Medium	Hemlock-Northern hardwood	chemical/biological
Summit Area Visitor Center	56*	3.2	N	0		High natural and cultural value, trails-potential hazard trees	Hemlock-Northern hardwood	chemical/biological
Summit Area Picnic Area	266*	3	N	0		High natural and cultural value, trails-potential hazard trees	Hemlock-Northern hardwood	chemical/biological
Summit Area Picnic Area	143*	4.8	N	0		High natural and cultural value, trails-potential hazard trees	Hemlock-Northern hardwood	chemical/biological
Summit Area	157	3.7	N	0	Healthy -New Growth	Medium	Hemlock-Northern hardwood	chemical/biological
Summit Area	70	0.4	**	**	**	Medium-low	Hemlock-Northern hardwood	

Location	Stand Number Surveyed	Park Acres	Relative[1] HWA Density/tree within Stand	Stand[2] Level Infestation (% trees infested)	Tree Health	Priority	Stand Type	Treatment Options
Summit Area	71	3	**	**	**	Medium-low	Hemlock-Northern hardwood	
Summit Area	142	1.8	**	**	**	Low	Hemlock-Northern hardwood	
Incline 6 to 8	35	8.4	N	0	Healthy -New Growth	Medium trail-potential hazard trees Altoona City (water) Authority, no chemical treatments	Hemlock-Northern hardwood	biological
Incline 6 to 8	33	19.4	N	0	Healthy -New Growth	Medium trail-potential hazard trees Altoona City (water) Authority, no chemical treatments	Hemlock-Northern hardwood	Biological
Incline 6 to 8	168	10.8	N-H	16	Healthy-New Growth, except trees w/HWA	Medium trail-potential hazard trees Altoona City (water) Authority, no chemical treatments	Hemlock-Northern hardwood	Biological

Location	Stand Number Surveyed	Park Acres	Relative[1] HWA Density/tree within Stand	Stand[2] Level Infestation (% trees infested)	Tree Health	Priority	Stand Type	Treatment Options
Incline 6 to 8	171	5	L-H	100	Stunted Tip Growth	Medium trail-potential hazard trees Altoona City (water) Authority, no chemical treatments	Hemlock-Northern hardwood	biological
Incline 6 to 8	47	4.4	**	**	**	Low	Hemlock-Northern hardwood	biological
Muleshoe Area	177	5.2	L-H	100	Stunted Tip Growth	Medium trail-potential hazard trees Altoona City (water) Authority, no chemical treatments	Hemlock-hardwood sugar maple floodplain	biological
Muleshoe Area	32	2.3	M-H	100	Stunted Tip Growth	High unique stand type	Dry hemlock-oak	chemical/biological
Incline 9 Area	184	5.8	L	100	Healthy -New Growth	Medium trail-potential hazard trees	Hemlock-tuliptree-birch	chemical/biological

Location	Stand Number Surveyed	Park Acres	Relative[1] HWA Density/tree within Stand	Stand[2] Level Infestation (% trees infested)	Tree Health	Priority	Stand Type	Treatment Options
Incline 9 Area	185	2.6	L-M	100	Healthy -New Growth	Medium trail-potential hazard trees	Hemlock-Northern hardwood	chemical/biological
Foot of Ten Area	118	0.9	N-H	100	Healthy -New Growth	Medium	Hemlock-Northern hardwood	chemical/biological
Foot of Ten Area	204	10.2	H	100	Stunted Tip Growth	High close to private residences potential hazard trees, unique stand type	Dry hemlock-oak	chemical/biological

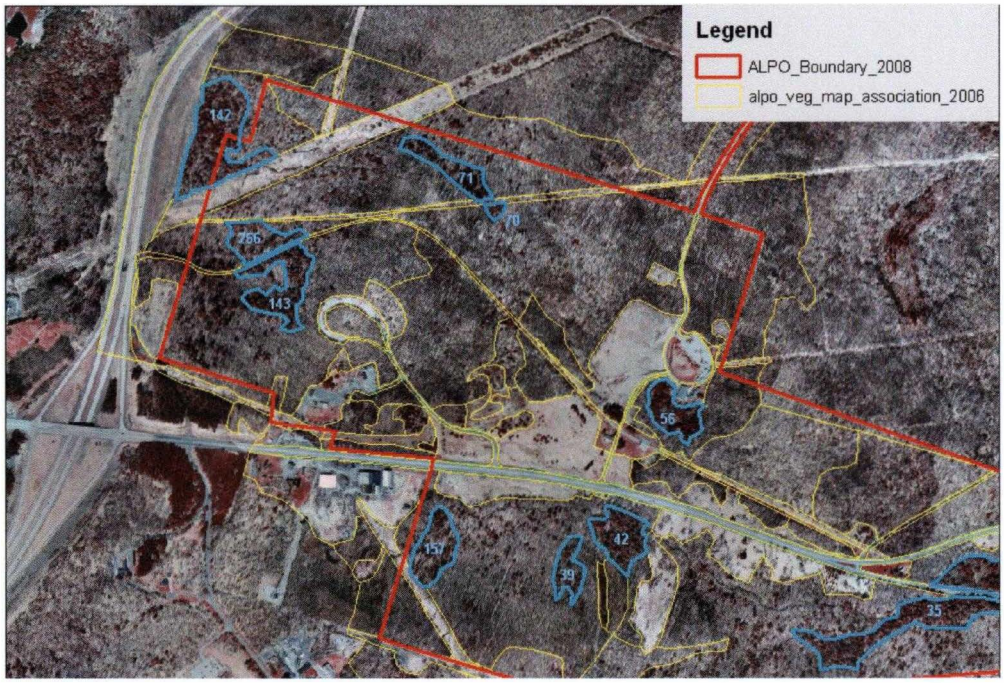
* = Surveyed by Park personnel
** = Stand not surveyed
[1] = HWA infestation densities were designated by visually inspecting each branch sample based on an estimated percentage of tips with adelgid present and categorized as follows:

Heavy (H) = >50% infested
Moderate (M) = 50% to 25% infested
Light (L) = <25% infested
None (N) = 0% infested

[2] = % of trees infested estimated using Costa/Onken sampling method

Figure 4a. Hemlock stand locations at Alleghany Portage Railroad National Historic Site, PA. ***(Maps provided by ALPO)***

Hemlock Stands at ALPO Summit Area
(outlined in blue)



Hemlock Stands at ALPO Inclines 6 to 8
(outlined in blue)

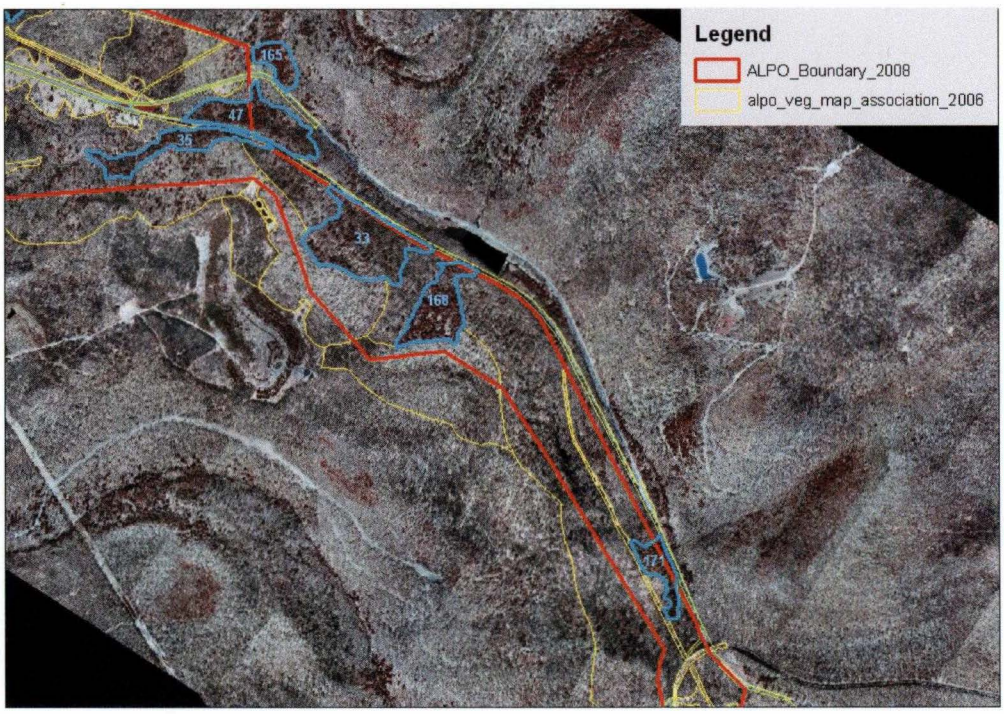
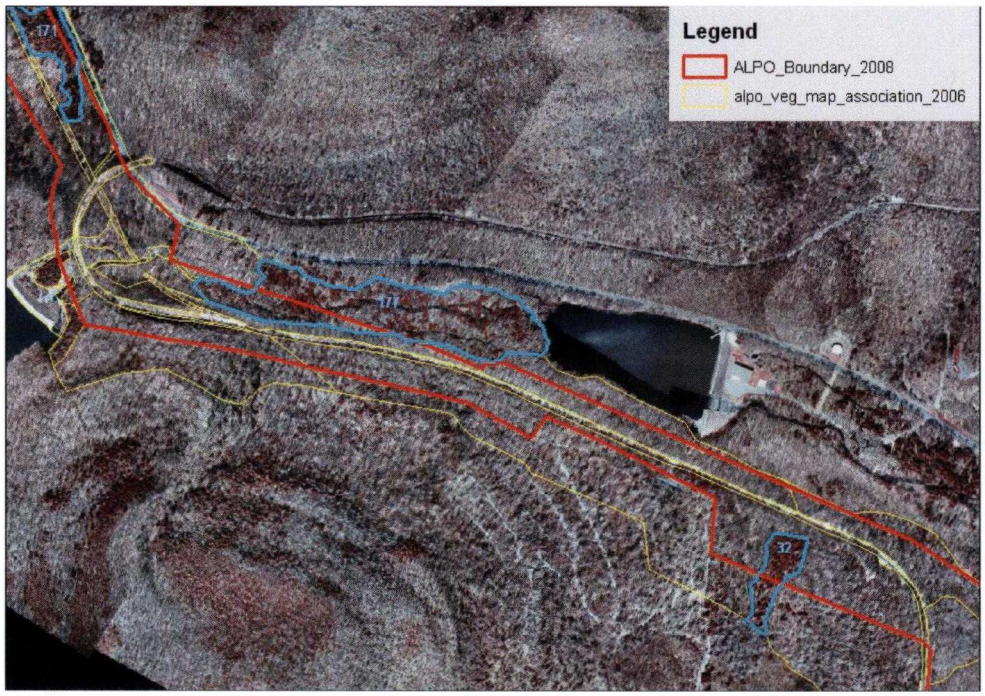


Figure 4b. Hemlock stand locations at Alleghany Portage Railroad National Historic Site, PA . *(Maps provided by ALPO)*

Hemlock Stands at ALPO Muleshoe Area
(outlined in blue)



Hemlock Stands at ALPO Incline 9 Area
(outlined in blue)

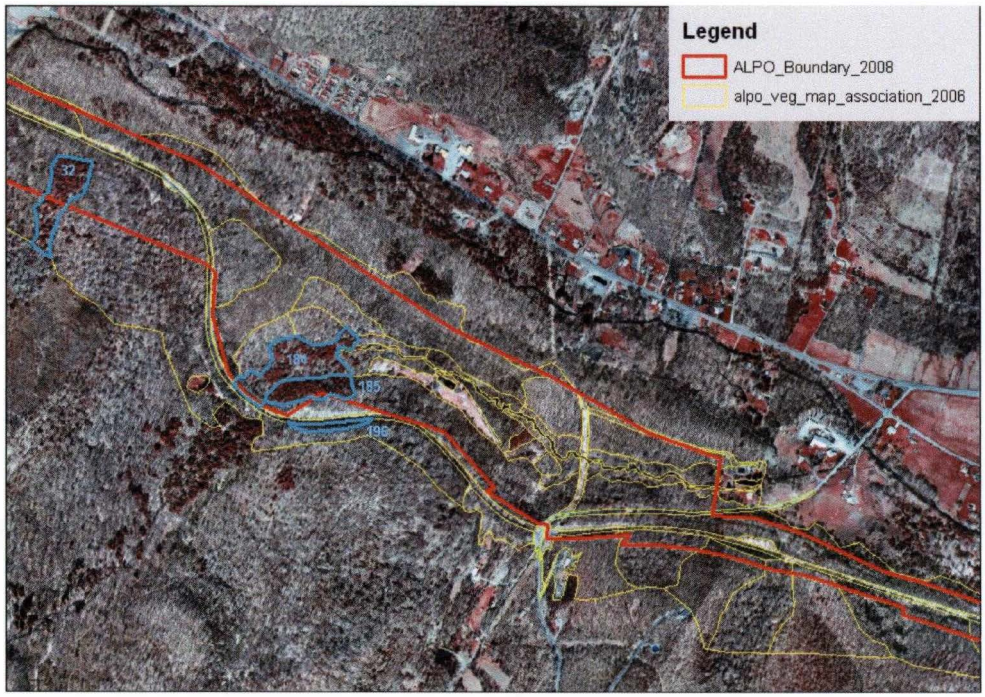
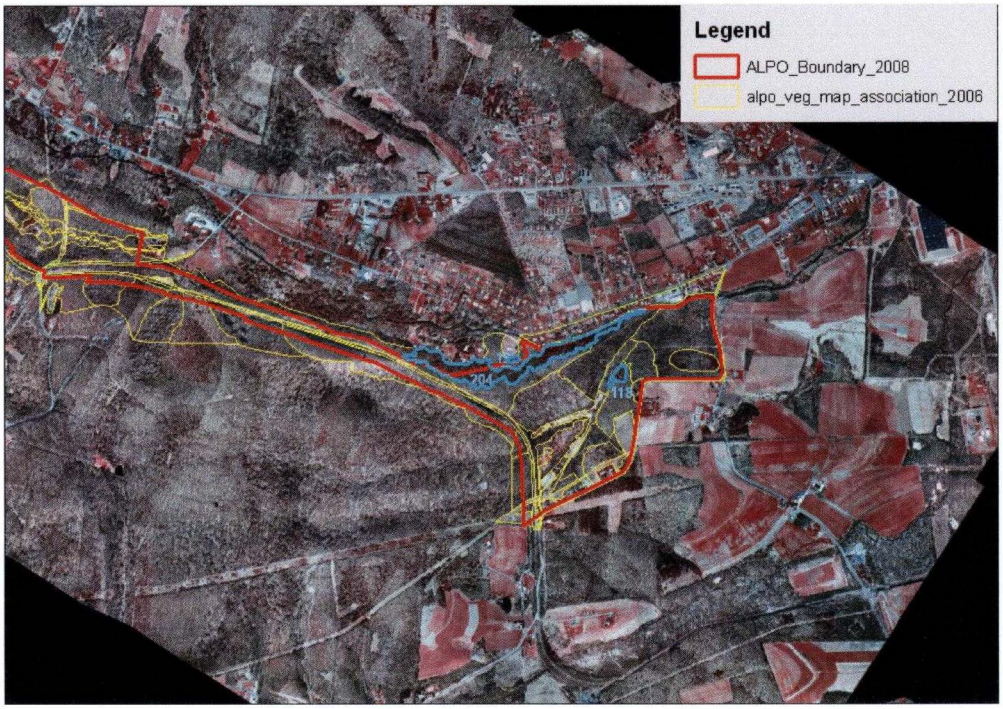


Figure 4c. Hemlock stand locations at Alleghany Portage Railroad National Historic Site, PA . *(Maps provided by ALPO)*

Hemlock Stands at ALPO Foot of Ten Area
(outlined in blue)



DISCUSSION

Hemlock stands located in the middle of Incline 6 to 8 and continuing southeast to the Foot of Ten area have established HWA populations. Population densities in these areas ranged from very light to heavy. Hemlock trees with HWA in stands 204, 32, 171, and 168 exhibit stunted tip growth and dieback. Consequently, impacts to hemlock resources at ALPO can be expected to increase.

Predicting year to year changes in HWA densities is difficult because of the dynamic nature of the many variables involved. Factors such as future climatic conditions, changing micro habitat (tree and site) conditions and other biotic and abiotic factors affect both survival and fecundity of HWA. Residual HWA populations as of June 2009 however, are likely to continue to increase and cause tree decline and mortality if no intervention is pursued in the near future.

MANAGEMENT CONSIDERATIONS

Chemical management options for protecting hemlock stands are limited by the biology and feeding behavior of HWA, pest population densities, site conditions (i.e. proximity to streams), accessibility and the treatment methods currently available. Insecticide treatments although effective, are conducted on an individual tree basis which can be both labor intensive and costly. Thus treatment strategies are typically focused in high value sites such as recreational or scenic areas or where hemlock stands have an important ecological, historic or aesthetic role or genetic preservation is a high priority. Classical biological controls such as predators and pathogens are being pursued by the USDA Forest Service but will likely take years to become effectively established. As such, preservation of hemlocks in the short term will require intensive monitoring and periodic chemical treatments when infestations are discovered.

Foliar chemical treatments:
Aerial spray using horticultural oil or insecticidal soap is not an option because aerial sprays could not provide the needed "saturation" necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits. Application of insecticides using ground spraying equipment is generally limited to areas accessible to hydraulic spray equipment and areas where over spray or run off would not contaminate streams, lakes or ponds. Backpack sprayers could be effectively used for foliar treatment of infested seedlings and saplings to protect regeneration.

Systemic Insecticides:
Several systemic insecticides are labeled for adelgid control and can either be injected into the soil or the tree stem (e.g. imidacloprid (Merit 75®WSP), dinotefuran (Safari® 20 SG), and bidrin (Metasystox-R®) or implanted (e.g. acephate)) into hemlock trees.

Imidacloprid is by far the most common systemic insecticide being used to control HWA and is applied as a soil drench, soil injection or injected into to the stem of the hemlock tree. Systemic insecticides are absorbed and trans-located by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, McClure

1992a). Soil injection in sandy or saturated soils should be avoided as leaching of imidacloprid into the soil profile and groundwater (McAvoy et al. 2002) is a possibility. Soil injections immediately adjacent to creeks or other open waters and areas prone to frequent flooding should be avoided. The soil injection or soil drench methods of imidacloprid treatments can take several months for translocation to occur but typically has provided better consistency in treatment efficacy and is expected to provide control for 3 to 5 years.

Trunk-injected imidacloprid generally requires a week or longer to provide adelgid control, with protection lasting for up to 2 years (Tater et al. 1998, Silcox 2002). Imidacloprid formulated as a trunk injection is available under the trade names Pointer®, IMA-jet® and Imicide® and are labeled specifically for tree injection for the control of adelgids. Stem injections should not be used on severely stressed trees.

Another application method when using dinotefuran is treatment by a bark spray application Dinotefuran is much more water soluble. Dinotefuran has been shown to be effective within a few weeks after application, and is expected to provide control for at least 2 years.

Imidacloprid and dinotefuran are relatively new insecticides in the family of chemicals called neonicotinoids (Felsot 2001) in the chloronicotinyl subgroup (USDA Animal and Plant Health Inspection Service 2002). It has a mode of action similar to that of the botanical product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the nicotinergic receptor sites in the postsynaptic membrane of the insect nerve (USDA Animal and Plant Health Inspection Service 2002), mimicking the action of acetylcholine, and thereby heightening, then blocking, the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). This causes substantial disorder within the nervous system, leading in most cases to death (Mullins 1993, Smith and Krischik 1999).

Both imidacloprid and dinotefuran have been demonstrated to be of low risk to humans and non-targets when applied properly. The USDA Forest Service has completed a human health and ecological risk assessment for use in HWA treatment programs. Both assessments can be viewed at: http://www.nvo.com/sera_inc.

Biological control:

There are no known parasites of adelgids. There are three predatory beetles approved for release and each is unique in its dispersal, reproductive potential, feeding behavior, and suitable climate regimes. They are all very host specific. Where these natural enemies are released is the responsibility of state forest health specialists from each state and the USFS. All of the releases are in infested hemlock stands found primarily along the leading edge of the generally infested area, where hemlocks are still healthy and HWA densities have not yet overwhelmed the trees. The release and establishment of HWA natural enemies is not likely to provide short term control of HWA. It is considered to be a long term approach and will likely require a complex of natural enemies to maintain HWA below damaging levels. It may be years before these predators can self perpetuate sufficiently before any level of success can be determined.

The first predator beetle to be imported and released for biological control is a tiny, black lady beetle, *Sasajiscymnus tsugae*, from Japan. Since 1995, over 2 million *S. tsugae* beetles have been released in over 200 sites in 16 eastern states from Georgia to Maine. The recovery of *S. tsugae* beetles in the years following release have been sporadic. The number of beetles

recovered have rarely been more than one or two per site. Adult beetles have been captured near some of the release sites more than 6 years after release, and some more than 1/2 a mile from nearest release site.

Figure 5. Beetles released for biocontrol (left to right): *Sasajiscymnus tsugae* from Japan, *Scymnus sinuanodulus* from China and *Laricobius nigrinus* from Pacific Northwest.

The predatory beetle, *Scymnus sinuanodulus*, a lady beetle from China, has been released since 2005. More than 36,000 adult beetles have been released in eleven states. So far, few beetles have been recovered from the release sites.

A Derodontid beetle, *Laricobius nigrinus*, from the Pacific Northwest is also approved for release. Mass rearing of this predatory beetle began in 2003, and more than 100,000 beetles have been released in thirteen States. Recovery of *L. nigrinus* has been confirmed at most sites. At some release sites, adult beetles are easily found and hundreds of larvae have been recovered.

Preferred release sites are newly infested sites where trees and adelgids are still healthy. Older infested sites where adelgid densities are low and recovery of hemlock trees is evident has also proven acceptable. Predator beetles are laboratory reared and the number of predators available in any given year is variable depending in part, on the success of the rearing facilities to locate good quality host material for a food source. Artificial diets for continuous rearing are not yet available.

RECOMMENDATIONS

Systemic insecticide treatments using imidacloprid and dinotefuran are recommended for HWA control on accessible, individual, high-valued, infested hemlock trees in areas of ALPO that have been designated as a priority by the Park's resource manager. The release and establishment of predatory beetles is also recommended in infested areas designated by the Park for biological control.

Where possible, soil treatments are preferred over stem injections as they offer more consistency in treatment efficacy, offer longer protection, easier to apply and are more economical. Imidacloprid applied at 0.75 grams of a.i. per inch of trunk diameter (dbh) is recommended for the soil injections,

Figure 6. Soil injections being performed with the Kioritz soil injectors and Merit 75WSP.

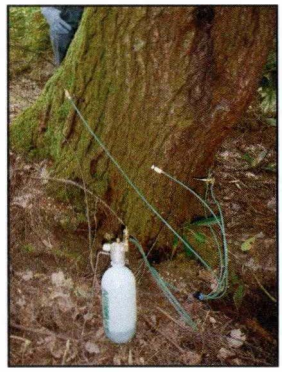


Figure 7. Chemical treatment using the Arborjet "Tree IV" system using Imajet insecticide.

and treatment timing should be in the spring or fall. In areas where soil treatment cannot be performed the insecticide recommended for stem injections is IMA-jet® at 5% active ingredient and applied using the Tree IV system.

Dinotefuran is more expensive than imidacloprid and would be best used on heavily infested trees already showing signs of declining tree health. Either basal spray or soil treatments are recommended at the lowest labeled dosage (3 grams/inch dbh). In circumstances where rocky porous soils exist trees should be treated using a basal spray.

Treated trees should be marked in a manner that will identify the year they were treated, such as a basal spray of color coded paint or tags since theses treatments should provide at least 2-5 years of control and treatments on neighboring trees in subsequent years may be desirable.

Ground spraying using horticultural oil to protect hemlock seedlings and saplings by means of a backpack sprayer should be considered in areas where protecting younger hemlocks is desirable and where over spray or run off would not contaminate streams, lakes or ponds. One or two applications of a 2% solution of horticultural oil applied in early summer or early fall is recommended as adelgids have not yet developed the wool covering that can impede penetration of the insecticide.

The establishment of natural enemies is also recommended and offers the opportunity for long-term control and may minimize the need for repeated chemical treatments in future years. Predatory beetle releases take place in the spring or fall of the year when HWA are actively feeding. The Morgantown Field Office will notify the park when beetles will be available and conduct their release and monitoring.

Resource managers should annually monitor tree health conditions, adelgid population densities and treatment efficacy. Effective management of HWA requires a vigilant monitoring and treatment program until sufficient biological control agents are established.

REFERENCES

Akerson, J. and G. Hunt. 1998. HWA status at the Shenandoah National Park. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 10-11.

Annand, P.N. 1924. A new species of *Adelges* (Hemiptera: Phylloxeridae). Pan-Pac. Entomol. 1: 79-82.

Bair, M.W. 2002. Eastern Hemlock (*Tsuga Canadensis*) Mortality in Shenandoah National Park. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 62-66p.

Baker, W.L. 1972. Eastern forest insects. USDA, Forest Service. Miscellaneous Publication No. 1175. 642 p.

Bentz, S.E., L.G.H. Riedel, M.R. Pooler, and A. Townsend. 2002. Hybridization and self-compatibility in controlled pollinations of eastern north American and asian hemlock (*Tsuga*) species. Journal of Arboriculture 28(4): 200-205.

Costa, S. and B. Onken. 2006. Standardized Sampling for Detection and Monitoring of Hemlock Woolly Adelgid in Eastern Hemlock Forests. FHTET-2006-16. U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team; 11p.

Doccola, J.J. P.M. Wild, I. Ramasamy, P. Castillo, and C. Taylor. 2003. Efficacy of arborjet viper microinjections in the management of hemlock woolly adelgid. Journal of Arboriculture. 29(6): 327-330.

Drooz, A.T. 1989. Insects of eastern forests. USDA, Forest Service. Micellaneous Publication No. 1426. 608 p.

Felsot, A. 2001. Admiring Risk Reduction: Does Imidacloprid have what it takes? Agrichemical and Environmental News 186: 2-13.

Godman, R.M. and K. Lancaster. 1990. *Tsuga canadensis* (l.) Carr., eastern hemlock. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America, vol.1, conifers. USDA Forest Service, Agriculture Handbook No. 654. pp. 604-612.

Mayer, M., R. Chianese, T. Scudder, J. White, K. Vongpaseuth, and R. Ward. 2002. Thirteen Years of Monitoring the Hemlock Woolly Adelgid In New jersey Forests. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 50-60 p.

McClure, M.S. 1989. Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Ann. Entom. Soc. Am. 82:50-54.

McClure, M.S. 1992a. Effects of implanted and injected pesticide and fertilizers on the survival of Adelges tsugae (Homoptera: Adelgidae) and on the growth of Tsuga canadensis. Journal Econ. Entomol. 85(2) 468-472.

McClure, M.S. 1992b. Hemlock woolly adelgid. American Nurseryman 175(6): 82-89.

McClure, M.S. 1995. Managing hemlock woolly adelgid in ornamental landscapes. Bulletin 925. Connecticut Agricultural Experiment Station. 7 p.

McClure, M.S. 1996. Biology of *Adelges tsugae* and its potential for spread in the Northeastern United States. In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 16-25.

McClure, M.S. 2001. Biological control of hemlock woolly adelgid in the Eastern United States. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2000-08. 10 p.

McClure, M.S., S.M. Salom, and K.S. Shields. 2001. Hemlock woolly adelgid. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2001-03. 14 p.

Montgomery, M.E. 1999. Woolly adelgids in the southern Appalachians: Why they are harmful and prospects for control. In: Gibson, P. and C. Parker, (Eds.), Proceedings of the Appalachian biological control initiative workshop. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-98-14. 59 p.

Mullins, J.W. 1993. Imidacloprid: a new nitroguanidien insecticide. In: Duke, S.O., J.J. Menn, and J.R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society Symposium, ASC, Washington DC: 183-189.

Onken, B., D. Souto, and R. Rhea. 1999. Environmental Assessment for the release and establishment of *Pseudosymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for the hemlock woolly adelgid. USDA, Forest Service, Morgantown, WV.

Quimby, J. 1996. Value and importance of hemlock ecosystems in the eastern United States. In: S>M> Salom, T.C. Tigner, and R.C. Reardon, eds. Proceedings of the First Hemlock Woolly Adelgid Review, Charlottsville, VA, 1995. USDA Forest Service, Forest Health Technology Enterprise Team-Morgantown, WV. FHTET 96-10. pp1-8.

Schroeder, M.E. and R.F. Flattum. 1984. The mode of action and neurotoxic properties of the nitromethylene heterocycle insecticides. Pestic. Biochem. Physiol. 22: 148-160.

Silcox, C.A. 2002. Using imidacloprid to control hemlock woolly adelgid in the Eastern United States. In: Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 280-287 p.

Smith, S.F. and V.A. Krischik. 1999. Effects of systemic imidacloprid on *Coleomegilla maculate* (Coleoptera: Coccinellidae). Envir. Entomol. 28(6): 1189-1195.

Tattar, T.A., J.A. Dotson, M.S. Ruizzo, and V.B. Bruce. 1998. Translocation of imidacloprid in three tree species when trunk and soil injected. Journal of Arboriculture 24: 54-56.

USDA Animal and Plant Health Inspection Service. 2002. Draft. Use of Imidacloprid formulations for the control and eradication of wood boring pests: Assessment of the potential for human health and environmental impacts.

Van Driesche, R.G. S. Healy and R.C. Reardon. 1996. Biological Control of Arthropod Pests of the Northeastern and North Central Forest in the United States: A Review and Recommendations. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-19: 10.

Wallace, M.S. and F.P. Hain. 1998. The effects of predators of the hemlock woolly adelgid in north Carolina and Virginia. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 3.

Webb, R.E., J.R. Frank, and M. J. Raupp. 2003. Eastern hemlock recovery form hemlock woolly adelgid damage following Imidacloprid therapy. Journal of Arboriculture. 29(5): 298-302.

Yamasaki, M., R.M. DeGraaf, and J.W. Lanier. 2000. Wildlife habitat associations in eastern hemlock – birds, smaller mammals, and forest carnivores. In: Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, edited by K.A. McManus, K.S.Shields, and S.R.Souto. pp.135-141.